Chapter 22

REDUCTION OF MAINTENANCE BY PROPER ORIENTATION OF SHIP CHANNELS THROUGH TIDAL INLETS[1]

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ABSTRACT

The inherited courses of some bay-port ship channels take them through tidal inlets along courses running across dominant directions of strong current movement and scour, or on courses that upset the natural tidal regimes. Such discordance may make necessary excessive maintenance dredging. Geological study of a section of the Texas coast shows that, in a unit coastal environment, there may be a predictable stable position of a tidal inlet and a common stable orientation for its channel which might better have been used for the ship channel outlet. Among probable damages to the natural environment resulting from a wrong orientation is excessive sedimentation in the inlet channel.

Engineering studies are needed to determine the economics of re-orientation and relocation of misfit channels of the type described.

The tidal inlet or "pass" is the central channel of a tidal delta. The delta is an enlargement of a barrier sand island at a gap where tidal and other flow into and out of large inland water bodies forms a strong local field of force with a longshore sediment drift and current. Engineering works in this field of force should utilize its characteristics, not fight them. As the coastal section studied here is only one of many, extension of the geologic study, with accompanying engineering studies, should be made to permit general laws of inlets, tidal deltas and barrier islands to be set up for both geology and engineering.

INTRODUCTION

THE TIDAL INLET OR "PASS"

The oceanic entrances to most harbors where a barrier island[2] of sand is encountered a few miles offshore are usually located at natural tidal inlets or "passes". In the natural state, such an inlet has a deep natural channel terminated at each end by a so-called "bar", Fig. 1. Many tidal inlets migrate.

Geological studies on the Texas coast suggest remedies for some of the difficulties in maintaining ship channels through inlets. Such studies might be used as guides in channel location and orientation on other coasts where similar conditions are found to exist.

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[1]The Agricultural and Mechanical College of Texas, Department of Oceanography, College Station, Texas. Contribution No. 12.

[2]Synonym: Barrier beach. Improperly: "Offshore Bar".

ACCIDENTAL CHOICE OF LOCATIONS OF "IMPROVED" SHIP CHANNELS

Historically, most improved ship channels have followed in general the passageways used by early shallow-draft shipping, being tied down to installations of the earlier period. When "improvements" of the channels were attempted, the locations of channels and harbors and the engineer's own choices of "best" routes were in some cases such as to bring him and his works into conflict with the existing equilibria developed between exceedingly strong natural forces.

STABILIZATION AND MAINTENANCE OF INLETS

To prevent migration of inlets used for ship channels, engineers have built retaining walls or revetments along one or both sides. To remove the bars, frequent dredging has to be carried on, as the "bars" tend to re-form after removal. Jetties help but cause beach erosion.

REDUCTION OF ENGINEERING COSTS BY APPLICATION OF GEOLOGIC PRINCIPLES

RELOCATION OR REORIENTATION

Artificial stabilization and continued maintenance of some ship channels through tidal inlets is very costly. It is possible that some such excessive maintenance operations are due to (1) wrong location of channel, (2) wrong orientation of pass through barrier island. Where one or both of these conditions seems to occur - for example, the Corpus Christi ship channel and Aransas Pass, Texas - combined engineering, hydrologic and geological studies are needed to determine whether there is a remedy. The questions arise: (1) if the pass were reoriented, or (2) if the channel were relocated, would there be a great enough saving to amortize the cost of the change? Some maintenance costs are shown in Table 1.

ASSISTANCE FROM GEOLOGY

On some coasts, geologic study shows (1) that stable channel locations can be found where the tendency of the inlet to migrate is absent, and (2) that, regardless of location, passes can be oriented, or re-oriented, so as to permit maximum natural flow through them, with presumed reduction of sedimentation in the channel. Reduction of the tendency of inlets to migrate and full utilization of natural currents should greatly reduce the costs of both original construction and maintenance. It would be the task of the engineer to determine whether the routes necessary to use these physically preferable locations for access to specific harbor sites would be economically desirable.

TIDAL DELTA - KEY TO GEOLOGICAL SOLUTION OF PROBLEM

It is evident from the constant movement of large masses of sediment along the courses of tidal inlets and their accumulation behind jetties that the inlet lies in a strong field of force. What is this field of force and what are its directions and magnitudes? Knowing these, we should be able to attack specific problems in the field with some confidence of success.

TABLE 1

SOME SHIP-CHANNEL DREDGING COSTS - TEXAS COAST

Place	Millions Yds.	Millions $	Years	Miles	Yards/Year
HOUSTON	119	13.0	25	51	4,750,000
CORPUS CHRISTI	32	4.5	16	21	2,000,000

	$/Year	Mile/Year	
HOUSTON	520,000	87,000 yds.	$12,000
CORPUS CHRISTI	275,000	100,000 yds.	$13,000

Figures showing what portions of total yardage and costs figures apply to maintenance of channels through tidal deltas alone are not available. Although the above figures suggest that the total maintenance is proportional to the mileage and is not greatly excessive for any one section over the average, yet we do not know how far along a channel excessive maintenance may be caused by difficulties originating in the tidal delta. The Houston and Corpus Christi channels are dissimilar in many respects and their maintenance costs may not be comparable for the purposes of this study.

The geologist recognizes the tidal inlet and its surrounding elevations, tidal flats and submerged contour irregularities as a tidal delta, Figs. 1, 2.

STUDY OF GROSS DYNAMICS OF TIDAL DELTA

The writer is not informed that a thorough going quantitative geophysical study of the hydrodynamic field of force of a tidal delta has ever been made. However, he has accomplished a geological study of the dynamics of the tidal delta from the study of a group of inlets and deltas. This has been done by studying the regional geologic and hydrodynamic setting and determining the origins, growth modifications, migrations and conditions of stability of the inlets and deltas, as well as the geological results of the attempts of engineers to control them. This study was made on the coast of Texas in the area shown in Fig. 3.

ANALYSIS OF TIDAL DELTA AND INLET

FORM OF DELTA

The simplest form of tidal delta would be symmetrical with respect to its inlet and centrally located opposite a large bay with a large volume of inflowing land runoff. Actually, most tidal deltas are highly asymmetrical, Figs. 2, 3, with a diagonal channel, offset oceanic shoreline and unequal lagoonward lobes. There seem to be no good examples of simple symmetrical tidal deltas on the coasts of the Atlantic or Gulf of Mexico. Asymmetry of a tidal delta seems to be due to the presence of a longshore drift. Hence we draw our typical tidal delta somewhat asymmetrical, Fig. 1. Galveston Bay would be a fair example. Pass Cavallo, Fig. 2, is representative of the section of coast here studied, Fig. 3.

The scarcity of symmetrical tidal deltas on the east coast of the United States indicates, as will be shown, that a longshore sediment drift is commonly present and is stronger in one direction than in the reverse.

All tidal deltas are double, formed by the deposition of sediment during both the inflow and outflow of tidal and other waters, Figs. 1, 2. The higher waves and stronger longshore currents at the oceanic end of the inlet cause the outer part of the delta to be broadly arcuate and only slightly protuberant, but the quiet waters of the lagoon and bay allow a large lobe to develop there on at least one side of the inlet.

Tidal inlets are normally centrally deep, Figs. 1, 3, but shallow at each end. The channel may divide around a central bar or island. The inner bar may be large and crescentic, Fig. 2. The bar-like front of the delta at the ocean may contain a very large yardage of sediment and appear merely as a broad shoals.

STABLE AND MIGRATING INLETS AND DELTAS

Tidal inlets and tidal deltas are either (1) migrating or (2) stable. From what we know historically on the coast of Texas and Louisiana, tidal inlets are occasionally opened during the high waters and great waves of hurricanes in situations where they are not stable. The new inlet may

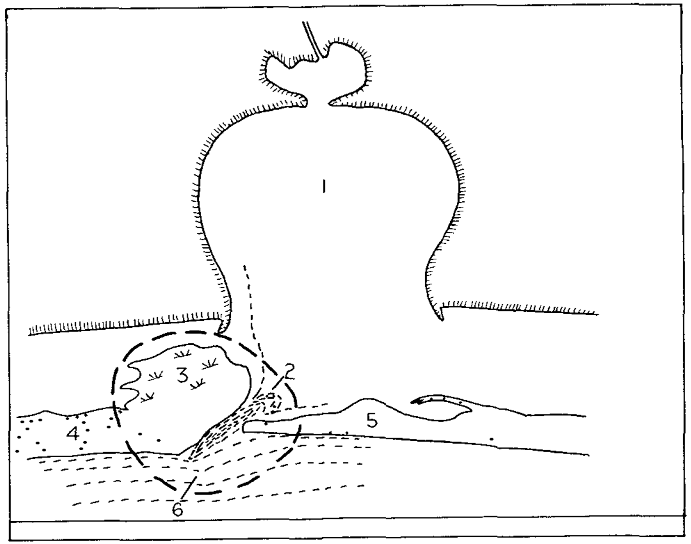

Fig. 1. A typical asymmetrical tidal delta.

Delta outlined by heavy broken line.
1. Bay with river entering inner end.
2. Inlet channel blocked at both ends by bars and shoals.
3. Down-drift lobe of delta, an expansion of barrier island.
4. Barrier island.
5. Narrow, pointed barrier island section on up-drift side of inlet.
6. Oceanic part of delta largely submerged, poorly developed.

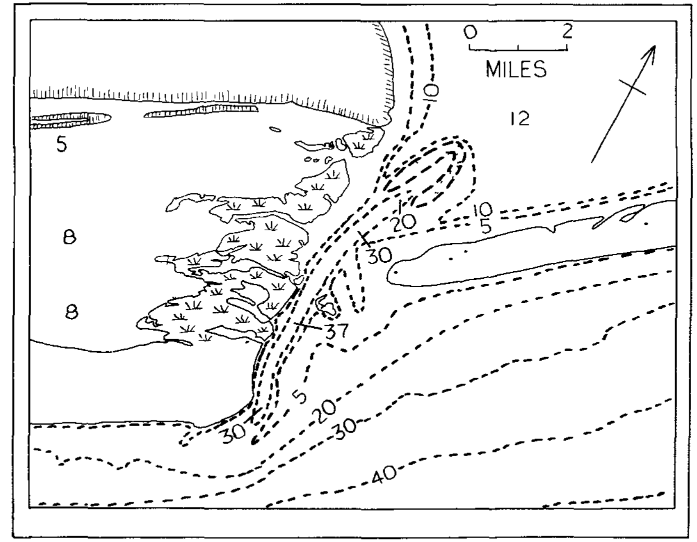

Fig. 2. Pass Cavallo and its tidal delta, Matagorda Bay, Texas.

A natural, asymmetrical tidal delta of Central Texas coast in the stable position. Crescentic channel bar across inner end, broad delta front across outer end. Inlet oriented NNE-SSW. Serrated islands of west half of delta show dominant drift in coastal lagoon. Barrier island strongly offset gulfward at down-drift side of inlet. Depths in feet below mean low water.

promptly sand up, or, much more rarely, it may establish itself with a typical deep central channel. The opening of a new inlet in a storm is probably the usual beginning of a period of inlet migration.

If not interfered with artificially or by the opening of further storm inlets, the newly established inlet will migrate slowly to a position of stability. Since the entire huge tidal delta moves with the inlet as a part of a single structure, the stable position of an inlet is marked by a heavy accumulation of sediment in the stable area. When a new inlet is formed by a storm at another point, the building of a new tidal delta begins, the former delta remaining stranded and its inlet slowly closing or becoming a shallow bayou.

DETERMINATION OF STABLE ORIENTATION AND POSITION*

Geologists can, by regional geological and meteorological studies, supported by adequate cartographic and historical data or at times in the absence of such data, determine the stable position of the tidal delta and, what is equally important, the stable orientation of the inlet channel in the delta. We will use the central coast of Texas as an example, for here the case is simple and clear-cut.

WIND DISTRIBUTION IN RELATION TO CONFIGURATION OF INNER AND OUTER SHORELINES

The wind regime of the coast of Texas is monsoonal, with the winds sub-equally divided in velocity and duration between the strong offshore and longshore northerlies (NW, N, NE) of winter and the equally strong and highly persistent onshore easterly and southerly winds (E, SE, S) of the warm and hot months. Only about 2 percent of the wind comes from westerly directions (W, SW). The heavy air of winter adds to the effectiveness of the northerly winds, nearly all of which are stormy and associated with the passage of a cold front. In our study, the longshore winds and wind components produce a strong longshore sediment drift in the coastal lagoon and along the Gulf shoreline. The offshore winds cause strong currents to course through tidal inlets - because of a funnel-shaped shoreline arrangement. Onshore winds check outgoing tidal waters and promote deposition of sediment at the Gulf end of an inlet.

DELTA MADE ASYMMETRICAL AND INLET CAUSED TO MIGRATE BY LONGSHORE SEDIMENT DRIFT

The coast of Texas southwest of the Brazos River mouth shows only asymmetrical tidal deltas, Fig. 3. The barrier island is narrow, low, bare and southwestwardly pointed on the eastern, up-current side of the inlet, but broad, lobate to triangular on the down-current side. The down-current side is always broad, may be built up high by dunes, and is commonly well stabilized by vegetation. The part protruding into the lagoon is usually low - less than 4-feet above sea - and largely marshy, grading off to broad flats and shallows that may essentially close the coastal lagoon.

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*The long-term average stability of axial position, here observed, may not prevent appreciable shifting of sediment in the inlet and at its ends.

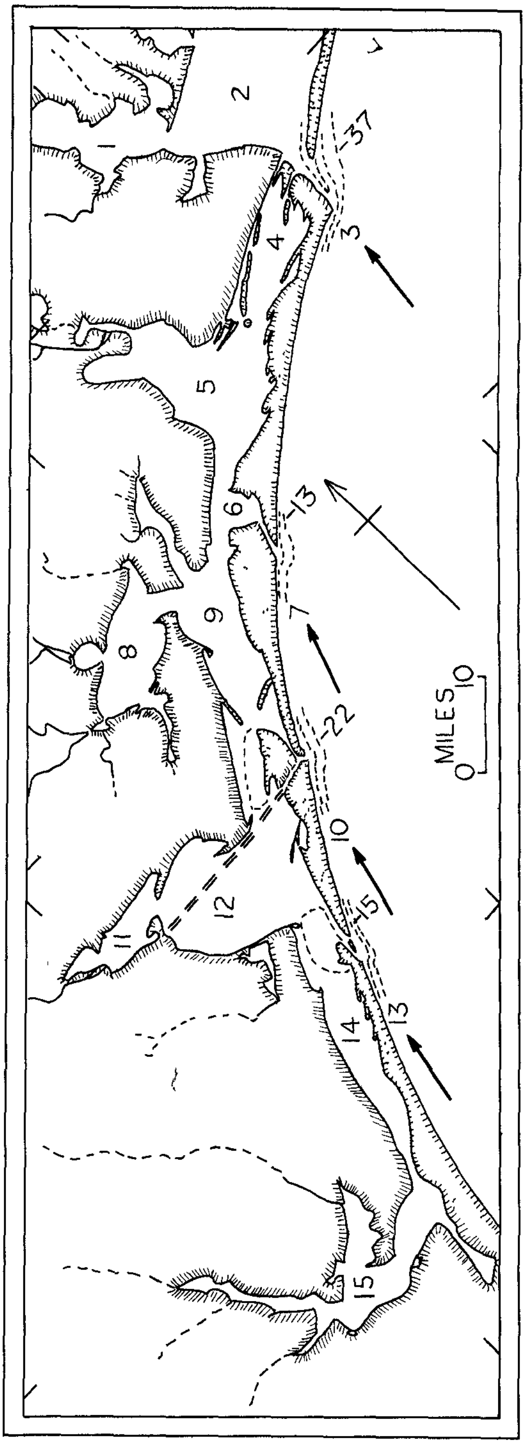

Fig. 3. Bays of central Texas coast with their natural tidal inlets and tidal deltas.

1, 2, Lavaca and Matagorda Bays. 3, Pass Cavallo (stable).
4, 5, 6, Espiritu Santo, San Antonio and Mesquite Bays.
7, Cedar Bayou Inlet (washover fans interfere).
8, 9, Copano and Aransas Bays. 10, Aransas Pass.
11, 12, Nueces and Corpus Christi Bays. 13, Former Corpus Christi Pass (slightly S of most stable position).
The Corpus Christi Ship Channel now connects 11 and 12 with 10.
14, 15, Laguna Madre and Baffin Bay, with no tidal inlet.
Original depths in natural inlet channels: -37, -13 feet, etc.

From Galveston Bay to Corpus Christi Bay records[3] show that the direction of migration of inlets before any were artificially stabilized was to the southwest. A study of F. C. Bullard (1942) of the appearance at the Gulf beach of the diagnostic minerals of the sands of the rivers of Texas confirms the evidence from inlet migration that the dominant longshore sediment drift is to the southwest.[4] Study of spits in the coastal lagoon shows the same drift direction there, Fig. 2.

It is evident that the longshore drift from the northwest carries the sediment into the inlet, without any possibility of storing materials at the near edge of the inlet. The sand merely moves along the Gulf shore to the inlet, where it becomes involved in the back-and-forth tidal movement. Sand also drifts across the inlet to the southwest. The southwest part of the delta grows, becoming excessively large, in the stable position. A condition that helped to make the northeastern part of each delta here thin and pointed is the diagonal, NNE-SSW natural orientation of the tidal inlet through a barrier island that trends northeast-southwest.

INLET LOCATION AND NNE-SSW ORIENTATION

The southerly locations and nearly north-south orientations of natural inlet channels on this coast, Fig. 3, are due to the repetition at each large, wide mouthed bay of a combination of conditions produced by (1) the occurrence of these bays north of the barrier island, (2) the presence of strong northerly winds which funnel water over these long fetches southward through inlets, (3) the direction of inlet migration, (4) the bearing of the barrier island, (5) the presence of a strong longshore sediment drift. Inlet migration to the southwest in conformity with the dominant longshore drift carries the delta and inlet south of the associated bay. "Northers" are dominant here during the winter monsoon. A funnel shape is provided by the angle between the southwest side of a northwest-elongated bay, the southwest-trending barrier island and its transverse inlet, Figs. 1, 2, 3. The great southward surge of the waters of the norther scours out the channel on a north-south or NNE-SSW axis conformable to the axis of the natural funnel just described. In some cases the southwardly and southwestwardly directed forces are so strong that the delta and inlet are driven down the coastal lagoon to an extreme, somewhat unstable position, as Cedar Bayou, Fig. 3.[5]

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[3]Galveston District Office, U. S. Engineers.

[4]This observation may not apply to local building of beaches behind jetties. The longshore drift may have its seasonal reversals and has a seeming local reversal on the northwest-trending north half of Rio Grande delta.

[5]This inlet has been obstructed by a strong development of washover fans.

On this particular coastal sector, the natural north-south orientation of inlets introduces an engineering conflict as it is diagonal to the trend of the barrier island and not on the shortest line across it. Yet the diagonal course is the equilibrium position in the deltaic field of force.

The strength and action of the heavily sediment-laden waters driven southward by the norther and their passage in a flood through the inlet has been studied and observed from the air by both the Galveston District of the U. S. Engineers and by the writer. A "norther" is the stormy passage of a cold air front over the prairies and the tidewater zone. For several days, as the front approaches the region, warm winds blow toward it from the south, roiling the bay waters, loading them with sediment and raising the level of the bays by water blown in from the adjacent coastal lagoon and by strong winds retaining part of the tidal prism of the bay.

With the arrival of the cold front, the wind is reversed and blows violently from northerly directions. Additional sediment is then picked up from banks and bottom. From the air, muddy water can be seen streaming southward from every shoreline projection and angle. The large prism of water previously accumulated in the bay by the southerly winds is now moved rapidly out through the funnel of the inlet by the northerly winds. Every year, drownings occur when fishermen in light boats are overturned by the racing floods that go through the passes. It is the strong movement of sediment out of the bays and southward along the coast with the northers that makes the southwestward longshore drift dominant in the yearly drifts and current movements. In the warm months, the strong, steady, southerly summer monsoon is unable to affect the inlets appreciably, because there is no funnelling action possible from the Gulf.

We conclude that meteorological factors combine with topographic factors in the coast of Figure 3, to orient natural inlets NNE-SSW and to move the inlets to positions south to southwest of the larger bays. These relationships are produced because the floods passing through the inlets from the north are adequate to orient an inlet channel along the axis of the natural funnel occurring at the position of inlet stability.

ONE INLET TO A BAY

Other features in delta and inlet histories need to be outlined to complete the support for assertions and interpretations made. Three lines of evidence show that only one inlet at a time survives for more than a short time for each bay: (1) Only one per bay now exists or has persisted for any Texas bay for an appreciable period. (2) During hurricane floods, scores of high-level washover channels form across the barrier islands, but do not become inlets except in rare cases. For example, former District Highway Engineer T. S. Bailey counted over 40 channels still discharging lagoon waters along Padre Island the day after a hurricane of the 1930s while the flood was still running off. The writer has studied these washover channels on the ground and in air photographs made before and after the 1930 hurricanes. These channels exist and have long existed as gaps in the dune wall of the island and have sanded up promptly at the beach level after each washover flood, the beach ridge being built across their outlets. Although all these channels were active in the 1930-1940 hurricanes and in others since, none led to the formation of an inlet. (3) Throwing the Corpus Christi ship channel into the natural inlet for Aransas Bay in 1924 led to the slow silting up of Corpus Christi Pass, in spite of occasional reopenings during hurricanes and by dredging. (4) Although artificial cuts were made through some of the washover channels by the Texas Game, Fish and Oyster Commission all quickly sanded up except the reopened natural inlet of Cedar Bayou.

The experience in Corpus Christi Bay showed that the tidal and other forces that keep the inlets active will support only one inlet at a time in a bay. Although there may for awhile be two adjacent openings, this is usually due to some temporary condition. Eventually one inlet will be established as deep and typical with a well-developed tidal delta, while the other will sand up and be closed. The wholly artificial Corpus Christi ship channel runs at right angles to both the tidal flow and the monsoonal winds. Moreover, this orientation gives the natural Aransas Pass inlet a dog-leg and has prevented it from reaching the position of stability which it had almost attained in 1887 when it was fixed by a retaining wall.

A CLOSED BAY SYSTEM

One of the persistent efforts of the Game, Fish and Oyster Commission to start a new tidal inlet was at Murdock Landing in the coastal lagoon southeast of the narrow opening of Baffin Bay. This bay is fed only by small creeks and intermittent arroyos and its narrow mouth is oriented so as to prevent the wind-driven waters of northers from impinging against the barrier island. Baffin Bay has not maintained a natural inlet during the century of map-making on this coast and it is evident from the topography that it has not done so for many centuries. It has two large washover channels, one being known as Boggy Slough. These have been shallowly open for short periods after hurricane floods or other excessively high tides.

STABLE POSITION OF INLET SSW OF WIDE-MOUTHED BAY

A single item remains to be established before we are ready to discuss reorientation and relocation again - the stable position of a tidal inlet and delta. Texas bays that have inlets are wide-mouthed and the inlets lie to the south or southwest of large bays. Inlets that seem to have been stable for centuries, judging from the large sizes of their deltas and the heavy build-up of dunes or spits on the south halves, are Cedar Bayou, Pass Cavallo and, before engineering interference, Corpus Christi Pass. Each of these inlets is located at an extreme southerly position with regard to the associated bay or suite of bays. Pass Cavallo, Fig. 2, has been stable since the recognizable accurate mapping by Cardenas in 1689, or 260 years (W. A. Price 1947, Fig. 2b).

Passes with histories of migration - all to the southwest - include Galveston Entrance, San Louis Pass and Aransas Pass. Deltaic changes have favored Brazos Santiago over Boca Chica at the southern end of the Texas lagoons.

MIGRATION PAST THE STABLE POSITION

Examination of the most southerly position taken here by natural inlets suggests that some of them may have been driven past the most stable position and have come again into a position of instability. This is indicated by the somewhat irregular courses of Cedar Bayou and old Corpus Christi Pass. The long, narrow and low point of the barrier island north of such insecure passes is vulnerable to washovers. Several such washovers at Corpus Christi Pass were in existance in 1875 when the first U. S. Coast Survey chart was made and have been intermittently open since. Pass Cavallo, however, seems highly stable. This is because the simple boundaries of its large bay seem to keep the tidal delta from migrating down the coast. However, the channel is thrown against the southwest bank, Fig. 2, and may be eroding there.

NORMAL LOCATION & ORIENTATION OF INLETS ON TEXAS COAST

Our studies have been confined largely to the southwestern Texas coast where the meteorological conditions are relatively simple and are known to the writer. Here, it is established that:

1. The stable orientation of a tidal inlet channel on this coast is NNE-SSW, giving it a long diagonal course across the barrier island, making the tidal delta asymmetrical and causing the southern side of the island to be offset gulfward.

2. Tidal inlets migrate to the southwest until they have reached a position of stability, but may be driven on past it into a second stage of instability.

3. Tidal deltas and tidal inlets have a stable position southwest of an associated series of wide-mouthed bays.

4. Only one inlet will long be naturally maintained for a single bay.

5. Artificial cuts through the barrier island producing dog-legs in the inlet, and channels run across the direction of tidal currents and dominant wind-driven currents, have high maintenance costs that may be due in large part to failure of the channel (1) to lie in the direction of greatest flow and (2) to be located at the stable inlet position for the region.

From casual observations of maps of other coasts with barrier islands, it is believed that their inlets can likewise be analyzed by the application of the geological methods.

DETERMINING STABLE LOCATION & ORIENTATION ON OTHER COASTS

It has been shown that a scientific study of all the inlets and deltas of a more or less homogeneous coastal sector has determined the stable position and stable orientation for its tidal inlets. The same methods may be applied to other sections of the coasts of North America and to similar coasts elsewhere. Differences in detail will be found but it is believed that most of the underlying principles have been determined, although not their full ranges of values.

WORLD-WIDE STUDY NEEDED TO COMPLETE KNOWLEDGE OF LAWS OF INLET DYNAMICS

Study of other coastal sectors with different fields of force and resulting different stable inlet positions should improve our knowledge of ship channel location. Such wide studies should permit general laws of inlets, tidal deltas and barrier islands to be set up, with a consequent improvement in the efficiency of engineering projects involving such coastal features.

POSSIBILITY OF REDUCING MAINTENANCE COSTS BY REORIENTING AND RELOCATING CHANNELS AND PASSES

REORIENTATION

To maintain a ship channel on an alignment contrary to the natural one would seem surely to result in excessive costs. If and where economically feasible, the pass through the barrier island should be reoriented so that, if there is a strong offshore water movement from the bays, it may be utilized to the full to scour out the inlet channel. This may not be practicable, where as at Aransas Pass, too sharp a dog-leg would be produced in an existing long ship channel.

RELOCATION

The question of relocation of a ship channel would have to be carefully approached, because of the great expense to be incurred where there is a long channel with costly industrial installations. Studies of many ship channels through inlets, possible supplemented by model studies, might be made in seeking a set of cost figures.

LOCATION OF NEW SHIP CHANNEL THROUGH A BARRIER ISLAND

In this case, geology has an evident opportunity to assist the engineer.

If the hydrodynamics of a tidal delta has not been carefully studied by engineers or oceanographers, such a study should be made in the hope that the deep breaching of the front of the delta (outer "bar") or a modification of the position of the front so as to throw it into deep water might be made. The maximum depth of the foot of the barrier islands is shown by the offshore profile of the bottom. It is usually from 20 to 35 feet. This would indicate how far offshore control of the delta would have to be established for a particular depth of channel.

CONCLUSIONS

1. Tidal inlets used as oceanic outlets for ship channels may be in a naturally stable position or may tend to migrate.

2. The tidal inlet is part of a tidal delta. The delta is the product of a strong hydrodynamic field of force in which there is a meeting of (a) tidal currents, (b) wind-driven currents from inner waters, and (c) longshore sediment drifts and currents of the coastal lagoon and the oceanic shore.

3. Laws of the tidal delta and inlet for the central Texas coast - a unit geo-oceanographic environment - have been deduced from a geologic, meteorologic and oceanographic study.

4. Study of other homogeneous sectors of coasts with bays and barrier islands are needed to complete our knowledge of the basic laws for inlets and deltas. These studies should be geologic, geophysical and engineering in type.

5. Many ship channels use locations inherited from the days of shallow-draft vessels.

6. Locations and orientations of bay-port ship channels that go through tidal inlets should be inspected to see whether there is a heavy maintenance cost that may be due partly to courses run in opposition to dominant natural forces.

7. Engineering studies may be made of such inlets and their deltas to determine (a) the possible saving in maintenance costs if the channel were reoriented or relocated, and (b) further economics of such changes. These studies should include other coasts, as noted in Conclusion 4.

8. Among geological results of the present study is the suggestion that tidal deltas may be normally asymmetrical due to the barrier islands of which they are an integral part usually having a strong longshore sediment-drift.

9. There is normally a seaward offsetting of the shoreline of the barrier island at the down-stream bank of the tidal inlet relative to the dominant longshore drift.

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